An Intercomparison of Near-surface Measurements with Aanderaa and AMF VACM Current Meters in Strong Tidal Currents

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AN INTERCOMPARISON OF NEAR-SURFACE MEASUREMENTS WITH AANDERAA AND AMF VACM CURRENT METERS IN STRONG TIDAL CURRENTS

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ABSTRACT

Smith, C., Lively, R.R., and Brown, K.C. 1984. An intercomparison of near-surface measurements with Aanderaa and AMF VACM current meters in strong tidal currents. Can. Tech. Rep. Hydrogr. Ocean Sci. 48: V + 36 p.

Six long-term (85 to 173 d) comparisons of near-surface (11-24 m) current and temperature measurements using Aanderaa (ARCM) and AMF-VACM current meters in the strong tidal circulation off S.W. Nova Scotia reveal:

(1) mean ARCM speeds over the entire mooring periods are enhanced by the order of 1 cm s^{-1} over the VACM while the mean directions differ by as much as 25° when the mean current is weak;

(2) the overall magnification of kinetic energy is limited to 10% because of the dominance of semidiurnal tidal energy whose measurement shows very little contamination;

(3) for a given pair of instruments, monthly mean statistics show a qualitative relationship between the ARCM/VACM ratios of current speed or variance and wind speed or stress variance. However, the differences in the level of contamination among the various instrument pairs, even those from moorings at the same site in the same season, preclude "calibration" of near-surface ARCM speeds in terms of environmental variables. Upward biases of ARCM speeds are generally in the range of 0-2 cm s^{-1};

(4) energy spectra show enhancement of ARCM variance in both the subtidal ($f<.7$ cpd) and high frequency ($f>3$ cpd) ranges. These discrepancies are worst in the most energetic (inshore) region of the tidal regime where high dissipation reduces nontidal variance to make the contamination more pronounced; and

(5) temperature measurements agree to within the manufacturer's specification.

RÉSUMÉ

Smith, C., Lively, R.R., and Brown, K.C. 1984. An intercomparison of near-surface measurements with Aanderaa and AMF VACM current meters in strong tidal currents. Can. Tech. Rep. Hydrogr. Ocean Sci. 48: V + 36 p.

Six comparaisons à long terme (85 à 173 jours) de mesures du courant et de la température près de la surface (11 à 24 m) effectuées au moyen de courantomètres Aanderaa (ARMC) et AMF-VACM dans la forte circulaton tidale au large du sud-ouest de la Nouvelle-Ecosse révèlent que:

(1) les vitesses moyennes mesurées au moyen du ARCM pendant toute la période d'ancrage étaient de 1 cm s^{-1} supérieures à celles mesurées au moyen du VACM et que les directions moyennes mesurées différaient par un écart atteignant 25° lorsque le courant moyen était faible;

(2) l'amplification globale de l'énergie cinétique était limitée à 10% en raison de la dominance de l'énergie de marées semi-diurnes dont les mesures ne présentent que très peu d'erreurs;

(3) pour une paire donnée d'instruments, les statistiques mensuelles moyennes indiquent une relation qualitative entre les rapports ARCM/VACM de vitesse ou de variance du courant et de vitesse du vent ou de variance de l'effort du vent. Toutefois, les différences d'erreurs entre les diverses paires d'instruments, même entre celles amarrées au même endroit pendant une même saison, empêchent un "étalonnage" des vitesses ARCM près de la surface en termes de variables environnementales. Les décalages vers le haut des vitesses ARCM sont généralement de l'ordre de 0 à 2 cm s^{-1};

(4) les spectres d'énergie indiquent des variances ARCM supérieures dans les gammes subtidale ($f<0,7$ cpd) et de haute fréquence ($f\geq 3$ cpd). Ces différences sont les plus prononcées dans le secteur des plus grandes énergies (avant-plage) du régime tidal où la dissipation abaisse la variance non tidale pour accentuer les erreurs; et

(5) les mesures de la température concordent avec les spécifications du fabricant.

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1. INTRODUCTION

The problem of making accurate long-term measurements of horizontal current at a fixed position near the ocean surface is extremely difficult. Because of energetic high-frequency motions in the surface layers, records produced by conventional moored current meters are subject to various forms of contamination which depend on the type of instrument, the mooring configuration, and environmental conditions such as wind, wave and current fields. The Aanderaa recording current meter (ARCM), the primary current-measuring device at BIO, measures current speed with a 10 cm Savonius-like rotor (Savonius, 1931) which is known to perform poorly in the presence of high-frequency fluctuations. This type of rotor will rectify oscillatory motion in the horizontal plane because it accelerates more rapidly than it decelerates ("overspeeding," Fofonoff and Ercan, 1967). In addition, the Savonius rotor will spin in the presence of a vertical oscillation induced by wave action and/or mooring motion even when no horizontal flow is present ("rotor pumping", Gaul, 1963; Kalvaitis, 1974). Another problem with ARCM measurements is associated with the method it uses to sample direction with its large (100x36 cm) trailing-fin vane. Saunders (1976a) estimates the time constant of the ARCM vane to be 8 sec. which means it does not respond well to the oscillatory motion produced by surface waves which have comparable periods. Instead the vane tends to remain in the direction of the mean current where its orientation is measured only once each sampling interval (1/2 hr) and combined with a rotor speed enhanced by the orbital velocities of the waves. Errors from each of these sources produces a current measurement which is larger than the true current and extends over the entire spectrum of variability including the mean flow.

To circumvent these problems the first vector-averaging current meter (VACM) was developed in 1971 at Woods Hole Oceanographic Institution. This device also measures speed with a 10-cm Savonius rotor but direction is sensed by a small (17x9 cm) vane with a 1-sec time constant and the sampling strategy is very different. Every eighth of a revolution of the rotor, the compass and vane orientations are measured and combined to give a discrete current direction which is then converted to Cartescan velocity components. For the duration of the sampling interval, these components are summed to produce a true vector-average velocity measurement over a number of intermediate samples which is then proportional to current speed. This scheme has the effect of sharply reducing the contamination associated with surface wave noise as suggested by a several field intercomparisons and laboratory studies.

A number of investigators have used in situ intercomparisons of ARCM, VACM and other instruments to evaluate their ability to measure near-surface currents. Under moderate wind and wave conditions, Halpern et al. (1974) showed that reliable measurements at frequencies lower than 2 cph could be made by VACM and ARCM at 16 to 20 m provided all components of the subsurface mooring were below the surface wave zone (i.e. greater than 15 m). However, Halpern and Pillsbury (1976a) found that mooring motion could severely contaminate deep (43 m in 50 m depth) ARCM measurements when the subsurface float extended to within 3 m of the surface. Furthermore, a direct intercomparison in the surface layer (Halpern and Pillsbury, 1976b) reveals that, again under moderate conditions, ARCM kinetic energy estimates may be biased high with respect to the VACM by factors of 1 to 10. Saunders (1976a) also intercompared a VACM (10 m) and ARCM (12 m) on a surface mooring against ship-tracked drogued drifters (12 m). He found ARCM

mean speed enhanced by a factor of 2.3 and argued that the VACM was also subject to a 10% upward bias due to the small but finite lag time of the vane. Magnifications of that order were confirmed by the VACM intercomparison studies of Saunders (1976b) and Beardsley et al. (1977). The general conclusion of these studies is that VACM measurements in surface layer are reliable to ≈2 cm s^{-1} with an upward bias of order 10% (Halpern, 1980).

Finally, there is some reason to expect that the near surface performance of both the VACM and ARCM is improved in high current regimes. Field intercomparisons (Halpern and Pillsbury, 1976b) as well as laboratory studies indicate that the rectification effects associated with high-frequency motion are diminished as the ratio of its amplitude to the mean current speed decreases. For example, Weller and Davis' (1980) summary of laboratory calibrations suggests that VACM and ARCM errors range from 10% and 50-100% respectively to near zero as the ratio of steady to unsteady component of an artificial flow field increases from one to three. Thus by mooring either instrument in a strong surface current but deep enough to be removed from the most intense wave action, it may be possible to maintain a signal-to-noise ratio greater than 3 most of the time and thereby reduce the level of contamination.

The following describes a series of ARCM/VACM intercomparisons conducted in the strong tidal regime off S.W. Nova Scotia as part of the Cape Sable Experiment. The purpose of these measurements was

(1) to estimate errors in the ARCM due to high-frequency contamination, and

(2) to attempt to "calibrate" the ARCM measurements by seeking a consistent relationship between coincident records from the two instruments.

The hypothesis guiding this investigation is that strong tidal streams in this region will minimize the effects of surface wave contamination on near-surface ARCM measurements. Furthermore, for a fixed mooring design, it may be possible to relate quantitatively the degree of contamination to some environmental variable such as wind stress.

2. INSTRUMENTS AND METHODS

The mooring array for the Cape Sable Experiment are depicted in Figure 1. Seven intercomparison studies (Figure 2, Table 1) were conducted at mooring sites C1, C2 and C3 over a two-year period commencing in November, 1978. Unfortunately, instrument failures marred the wintertime deployments at C2 and C3, leaving only one partial comparison for currents during the winter period at C3 and two summer comparisons each at C1 and C2. A C2 winter comparison for temperature alone made a total of six trials.

The mooring configuration (Fig. 3) was designed to isolate the deeper measurements from surface wave action by placing those instruments on a separate wire below a mid-depth float. The near-surface measurements were made by a shackled pair of VACM and ARCM, nominally at 15 and 16 m, beneath a torpedo-shaped subsurface float at 13 m. The true depths of the instruments, to the nearest metre, are given in Table 2 and the actual separation between the two rotors was less than 1 m. The maximum currents measured at each site (1.0 m s^{-1} at C1, 0.8 m s^{-1} at C2, C3), diminished by 25% in the bottom 1/3 of the water column, have been used to estimate the "stiffness" of the mooring with a model for the static force balance. These results indicate that near the surface, the tilt of the mooring line from the vertical is the order of 10° and the resulting vertical

displacement of the instruments is less than 3 m.

The VACM rotor and vane are mounted along the vertical axis at the lower end of the instrument case. The vane heading relative to the housing is sensed by a vane follower through a magnetic coupling and a magnetic compass provides the orientation of the instrument with respect to magnetic north. Each 15-min sample consists of the east and north sums of the Cartesian velocity components, the total rotor count, the instantaneous compass and vane headings, a temperature and a time word provided by a crystal controlled clock. In processing the record, the average east (u_v) and north (v_v) components of velocity, the vector speed [$S_v = (u^2_v + v^2_v)^{1/2}$] and direction [$\theta_v = \tan^{-1}(u_v/v_v)$], the scalar speed ($R_v$), temperature ($T_v$), and the instantaneus direction (ϕ_v) are calculated. A complete description of the speed calibration and data recording techniques is given by McCullough (1975).

Free to swivel about the mooring line, the ARCM is aligned with the flow by the large trailing-fin vane attached to the case. The rotor is mounted on a vertical axis on top of the case and revolutions are transferred through the case by a magnetic coupling. This instrument also contains a magnetic compass for determining direction of the flow. At the end of each 30-min sampling interval, an electro-mechanical encoder records the average rotor count, compass heading, temperature, conductivity and pressure or time words on a 1/4 inch magnetic tape. The processed record contains the scalar speed (R_A), instantaneous direction (ϕ_A), temperature (T_A), conductivity (C_A) and pressure (P_A). Table 2 compares the manufacturer's specifications for the range and accuracy of the speed, direction and temperature sensors. Special procedures were required to insure the accuracy of the Aanderaa direction measurements (Keenan, 1979).

These included pre- and post-deployment compass calibratins which differed by less (maximum 3°) than the manufacturer's specification for directional accuracy.

Contemporaneous data from the two instruments were edited and velocity data were resolved or rotated into the offshore (U at 194° T) and alongshore (V at 104° T) directions. The 15-min VACM and 30-min ARCM time series were then smoothed with 5-pt. and 3-pt, respectively, running mean filters and subsampled at 1-hr intervals (the "1-hr" data). This procedure removes different amounts of energy at high frequency as indicated by the filter response functions in Figure 4. In the following analysis, spectral calculations have been corrected for this effect so that energy in the high frequency bands may be directly compared. The 1-hr data were also low-passed with a Cartwright filter (halfpower at 31 hr) to remove the tides and subsampled at 6-hour intervals (the "6-hr" data).

Processing of the VACM records, carried out by the Woods Hole Oceanographic Institution (WHOI), was not of the highest quality. In addition to U_V, V_V, T_V and time, the final 1-hr data set contained redundant variables, the vector-mean speed (S_V) and direction (θ_V), rather than scalar speed (R_V) and instantaneous direction (ϕ_V). This loss impaired the evaluation of instrument performance. In addition, the wrong magnetic variation had been applied so that all velocity data had to be rotated. Finally, there still appears to be a delay of 40-45 minutes in the start time of record C1(380, 15 m) as indicted by the phase of the 29-d M_2 tidal ellipses (Figure 5). A timing error also develops in the ARCM record, C1(380, 16 m), where the phase is delayed by roughly 30° during May, 1980. These problems are presently under investigation but have little bearing on the following results.

3. RESULTS

3.1 Record-Mean and Monthly Statistics

The overall statistics from the six successful trials are presented in Table 3. In spite of the vertical separation of the instruments, the average temperature differences are small and within the specified accuracies of the instrument. However, the magnitudes of the record-mean ARCM current, $\overline{S}_A$, are augmented by factors of 2 to 49% over the VACM levels while record-mean directions diverge by 7 to 25°. These differences are more easily seen in comparing the progressive vector diagrams (Figure 6) which reveal that the largest discrepancies occur where the flow is most weak and variable i.e. at C2(310). The amplification of the ARCM total current variance also reaches a maximum at this site, although the difference is less than 10%. Thus there appear to be inverse correlations between the VACM vector-mean speed, $\overline{S}_v$, and (a) the ARCM/VACM ratio of mean speed ($\overline{S}_A/\overline{S}_v$), (b) the ratio of current variance ($\overline{VAR}_A/\overline{VAR}_v$), and (c) the net divergence ($|\overline{\Delta\alpha}|$) of the vector-mean currents. These relationships are as expressed by linear regressions by:

$$\overline{S}_A/\overline{S}_v = 1.418 - .046\ \overline{S}_v \qquad (r=-.60) \qquad (1a)$$

and

$$\overline{VAR}_A/\overline{VAR}_v = 1.095 - .013\overline{S}_v \qquad (r=0.84) \qquad (1b)$$

and

$$|\overline{\Delta\alpha}| = 26.8 - 2.6\ \overline{S}_v \qquad (r=-.90) \qquad (1c)$$

The correlations (1b, c) are significant at the (.02, .01) levels, but (1a) is insignificant at 0.1 for the small number of degrees of freedom.

On a monthly basis, the ratio of ARCM to VACM current variance for

a given instrument pair appears to reflect the variability of the atmospheric forcing as measured by the variance of wind speed at Yarmouth (Figure 7a). For the summer periods, the ratios diminish to near unity as the rms wind drops to a level of 20 m s^{-1} (variance = 400 m^2 s^{-2}) then rise again in the fall as the wind picks up. The maximum amplification of ARCM variance (≈20%) occurs at C2(310) in April and October. In contrast, the variance ratio at C2(381) in the summer of 1980 does not vary significantly from unity. Similarly, results from the single early winter comparison at C3(359), though they reflect increases in the wind forcing, generally exhibit lower values of the variance ratio than found at C2(310). Thus mismatches in the level of response to wind thwart attempts to correlate the variance ratio with either wind speed or stress (Fig. 7b) to the extent that no clear relationship at a given site nor trend between sites has been found. Also, the true depth of the instruments does not seem to be an important factor.

This lack of correlation was also found between ratios of the monthly mean current speeds and wind speed or stress variance. Figure 7b reveals that the relative speed contamination is greatest in April at C1(309) and C2(310) but otherwise limited to roughly 20%. In absolute terms (Fig. 7c) the monthly current speed differences ($\hat{S}_A - \hat{S}_V$) are generally less than 2 cm s^{-1} and seem to bear no consistent relationship to the strength of the mean current, $\hat{S}_V$.

3.2 Spectral Analysis

The spectra of total current variance (2X kinetic energy spectra) for the five successful intercomparisons are displayed in Figure 8. The C1 spectra (Fig. 8a, b) naturally show the highest semi-diurnal tides, but also have significantly lower energy in the subtidal bands than C2 records from the same seasons (Fig. 8c, d). This is presumably due to enhanced

tidal dissipation at C1. The tidal energy at C3 is comparable to that at C2, but the subtidal energy is at least a factor of two higher because of the stronger atmospheric forcing in the winter season. All of the spectra fall off rapidly at high frequencies out to 0.5 cph, but significantly lower energy in these bands is found in the VACM records at C1.

Unlike the VACM spectra, the ARCM high-frequency energies at C1 are comparable to the levels at other sites. This gives rise to ARCM-VACM differences at C1 which are significant at 95% confidence. (Note that the 95% confidence levels, determined from the chi-squared distribution, are strictly applicable to each curve individually, but not to the difference between them since with two closely-spaced highly coherent records, we are comparing two measurements of the same realization rather than two independent realizations of the random process [Halpern et al., 1981]. The rms amplitude differences may be a more useful measure of similarity). High frequency enhancement is also evident in the C2 and C3 records but the differences are much smaller than at C1. The C1 records also exhibit magnifications of the subtidal energy which exceed those measured at the other sites. Figure 9 summarizes these differences in terms of the ratio of spectral energies measured in the various comparisons. The closest agreement ($\leq$10%) is found for estimates in the tidal bands which are indistinguishable at the 95% level. However, with the exception of a few high-frequency (low-energy) estimates at C2, the ARCM energy levels are consistently higher than those of the VACM. The high-frequency discrepancy at C1 amounts to a factor of 3 to 4 of the energy content in these bands.

3.3 Instrument Performance

The character of the differences between the ARCM and VACM current

measurements is revealed by comparing 5-day time series plots of ARCM scalar versus VACM vector speeds and directions. (The temperature records are indistinguishable to the specified accuracy of the instrument). The first five days of the records from C1(309) (Figure 10a) indicate that R_A exceeds S_v at both the maximum and minimum speeds. This difference is diminished particularly at high speeds in July (Figure 10b) when the atmospheric forcing is weakest, and partially restored by the beginning of October (Figure 10c). A consistent offset in direction of order 5 to 10° is also evident throughout these records particularly at maximum flood or ebb when the direction is nearly steady. This offset is consistent with the net difference (11°) in directions of the record-mean velocities and exceeds measured changes of 2 to 3° between the pre- and post-deployment compass calibrations for the ARCM.

A similar result is obtained for the speed comparison at C2(310) (Figure 11). The high biases of scalar with respect to vector speeds are found in Aprl and October, but the two are virtually identical in July. On the other hand, no directional offset is evident in these records despite a substantial divergence (-25°) between the record-mean current vectors.

At C3(359), the ARCM speed bias is <u>not</u> found in the October records (Figure 12a), but does appear near the end of the record in January (Figure 12b). This effect is clearly illustrated by comparing the scatter plots for R_A vs S_v based on the first and last 1000 cycles of the record (Fig. 13). The first part of the record shows only a small positive bias for R_A at low speeds whereas the latter part shows an increased bias which extends over the entire speed range. Note also in Figure 12 that a slight directional bias of -5 to -10°, especially at the beginning of the record, is consistent with the overall vector-mean difference of -15°.

Finally in an attempt to relate the speed bias to atmospheric forcing, cross spectral analyses (not shown) between Yarmouth 1-hr wind speed and stress versus (R_A-S_V) produces no significant coherence.

4. DISCUSSION

Results from six long-term intercomparisons of ARCM and VACM current meter measurements in the surface layer (11-24 m) of an energetic tidal circulation off Cape Sable, N.S. indicate magnifications of the ARCM record-mean speeds ranging from 2 to 49%. The relative errors are greatest when the current is weak (i.e.< 2 cm s^{-1}) and are generally less than 20% when it exceeds 3 cm s^{-1}. In absolute terms, the ARCM mean currents are biased upwards by the order of 1 cm s^{-1} for the mooring configuration used here, i.e. a subsurface float (nominally) at 13 m (Figure 3). These figures are comparable to those of Howarth (1981), who used a similar mooring, but are considerably better (by more than a factor of 2) than those found by Saunders (1976a) in comparing ARCM and VACM records from a surface mooring.

The differences of the record-mean directions from the two instruments also appear to vary inversely with the magnitude of the mean speed. However, examination of the individual records suggests that persistent direction offsets of order 10° may be related to residual calibration errors which lead to a net divergence. On the other hand, the large deviations ($15° \leq |\overline{\Delta\alpha}| \leq 25°$) at low speeds are not related to calibration errors, but rather to the difference in sampling schemes of the two instruments and an accentuated vane-response problem caused by the relatively low signal-to-noise ratio. A much larger discrepancy (68°) was found by Howarth (1981) in a similar context.

It has been suggested (Saunders, 1976a) that one signature of rectification errors associated with the Savonius rotor (i.e. "overspeeding" or "rotor pumping") or the ARCM sampling scheme is the difference between the scalar (R_A) and vector (S_v) speed measurements. Close examination of these records reveals that for a given instrument pair, the discrepancies between these two variables is largest when the atmospheric forcing is greatest and generally insignificant in summer when the forcing is minimal. However, the relationship between the degree of contamination and strength of the forcing cannot be quantified because various intercomparisons at the same site, in the same season, and using the same mooring configuration are not consistent with one another. This conclusion, based on direct comparisons of both hourly and monthly-mean values of R_A/S_v versus wind speed and stress variance, has been echoed by other investigators [eg. Beardsley et al. (1977), Howarth (1981)] who found no suitable environmental index of the quality or accuracy of the measured vector velocities. The 1-hr speed differences also bear no direct relationship to the strength of the measured currents. Thus although the overall level of errors may be assessed using correlations such as in (1), it is not possible to calibrate the Aanderaa current measurements either internally (eg. by the strength of current) or with respect to external variables (eg. wind speed or stress).

Because of the "polar" nature of the ARCM measurements (i.e. the vector components of velocity are nonlinearly related to the measured speed and direction), contamination due to high frequency motions is distributed over the entire spectrum of current variability. Moreover, for a given spectrum, the degree to which the spurious energy (noise) in a particular band stands out above the true background energy (signal) detected by the

VACM depends primarily on the level of the background energy. Thus the energy mismatches appear greatest in the subtidal and high-frequency bands of spectra from the shallow inshore zone (C1) where intense tidal dissipation reduces the background levels and thereby lowers the signal-to-noise ratio. On the other hand, spectral estimates at tidal frequencies are virtually identical. In deeper water the spurious energy is again distributed over the spectra, but the magnitudes of the discrepancies are not uniquely related to the site of the measurements or the strength of atmospheric forcing. Nevertheless, because of the dominant contribution of the tides to current variance, the overall enhancement of ARCM variability is limited to less than 10%. In contrast, Petrie (1977) found the current variance of a 20-m Braincon instrument (similar to ARCM) to be magnified by 55% over that from an Endeco current meter.

5. CONCLUSIONS

The major conclusions of this study are:

1) The amplification of near-surface ARCM current measurements from a subsurface mooring in the energetic tidal regime off S.W. Nova Scotia amounts roughly 1 cm s^{-1} in the record-mean current and less than 10% in current variance.
2) The mean directions of the ARCM over the deployment period deviate from the VACM vector-mean directions by 7 to 25° with the largest differences associated with minimum mean currents.
3) Spurious ARCM energy resulting from surface wave contamination is distributed over the spectrum but cannot be discerned in the tidal bands whose energy dominates the total current variance.
4) It is not possible to calibrate the degree of ARCM contamination

either internally or with respect to external forcing.

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TABLE 1. Instrument Pairs for Aanderaa RCM/VACM Intercomparisons

V A C M				A R C M			
Instrument Designation: Site (mooring no., depth)	Serial No.	Sampling Rate (min)	Time Period (days)	Instrument Designation: Site (mooring, depth)	Serial No.	Sampling Rate (min)	COMMENTS
C2(308, 20 m)	V-0500	15	Nov/Apr '79 (0)	C2(308, 21 m)	1039	30	VACM malfunctioned ARCM rotor lost
C2(309, 15 m)	V-0495	"	Apr/Oct '79 (158)	C1(309, 16 m)	816	"	ARCM failed d276
C2(310, 17 m)	V-0497	"	Apr/Oct '79 (173)	C2(310, 18 m)	1283	"	
C2(358, 13 m)	V-0245	"	Oct/Mar '80 (158)	C2(358, 14 m)	3569	"	VACM rotor broken, temperature only
C3(359, 11 m)	V-0498	"	Oct/Jan '80 (85)	C3(359, 12 m)	4299	"	ARCM lost rotor d13, 1980
C1(380, 15 m)	V-0497	"	Mar/Aug '80 (143)	C2(380, 16 m)	217	"	
C2(381, 23 m)	V0495	"	Mar/Aug '80 (149)	C2(381, 24 m)	3197	"	

TABLE 2. Manufacturer's Specifications for Aanderaa* and VACM** Instruments

Quantity	VACM	ARCM
Speed		
Range	2.6 to 308.8 cm s^{-1}	1.5 to 250 cm s^{-1}
Accuracy	not specified	± 1.3% or .5 cm s^{-1} +
Threshold	2.6 cm s^{-1}	1.5 cm s^{-1}
Direction		
Range	0°to 360°	0 to 360°
Accuracy	±2.8°	±5°
Temperature		
Range	not specified	-2.46 to 21.4°
Accuracy	±.1°C (±.01° calibrated)	±.1°C (±.0125° calibrated)

* Manufactured by Ivar Aanderaa, Bergen, Norway

** Manufactured by AMF Electrical Products Development Division, Herndon, VA.

\+ Tang and Hartling (1979)

TABLE 3. Overall Statistics for ARCM/VACM Intercomparisons

Site (Mooring)	Duration (days)	$\overline{S}_V$ ($\times 10^2$ m s^{-1})	$\overline{\alpha}_V$ (°T)	$\overline{VAR}_V$ ($m^2 s^{-2}$)	$\overline{T}_V$ (°C)	$\overline{S}_A/\overline{S}_V$	$\Delta\overline{\alpha}_{V-A}$ (°T)	$\overline{VAR}_A/\overline{VAR}_V$	$\Delta\overline{T}_{V-A}$ (°C)
C1(309)	158	7.35	245	.424	7.47	1.22	11	1.02	.05
C2(310)	173	1.86	132	.193	9.12	1.49	-25	1.09	-.01
C2(358)	162				6.02				.11
C3(359)	85	3.28	105	.211	6.37	1.12	-15	1.04	.01
C1(380)	143	7.04	252	.397	5.56	1.09	7	1.01	.02
C2(381)	149	5.54	287	.207	6.32	1.02	11	1.00	.06

$\overline{S}$ = magnitude of record mean current

$\overline{VAR} = \overline{VarU} + \overline{VarV}$ = current variance

$\overline{\alpha}$ = direction of record mean current

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3. Tri-anchor configuration for Cape Sable moorings located on the 110 m isobath (eg. C2, C3). Nominal depths for the shackled pair of VACM and ARCM instruments are 15 m and 16 m respectively. For C1 moorings, the depths of mid-depth and near bottom instruments were 30 and 50 m.

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7(a). ARCM/VACM ratios of monthly current variance for five Cape Sable instrument intercomparisons during 1979-80. Open symbols indicate averages over less than one month's data. Dashed curve represents monthly wind speed variance at Yarmouth, N.S.

(b). ARCM/VACM ratio of monthly mean current speed. Dashed curve represents monthly wind stress variance at Yarmouth, N.S.

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b) C1(380); March-August, 1980

c) C2(310); April-October, 1979

d) C2(381); March-August, 1980

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a) day 292-334, 1979 (cycle 1-1000)

b) day 334, 1979 - day 13, 1980 (cycle 1001-2044)

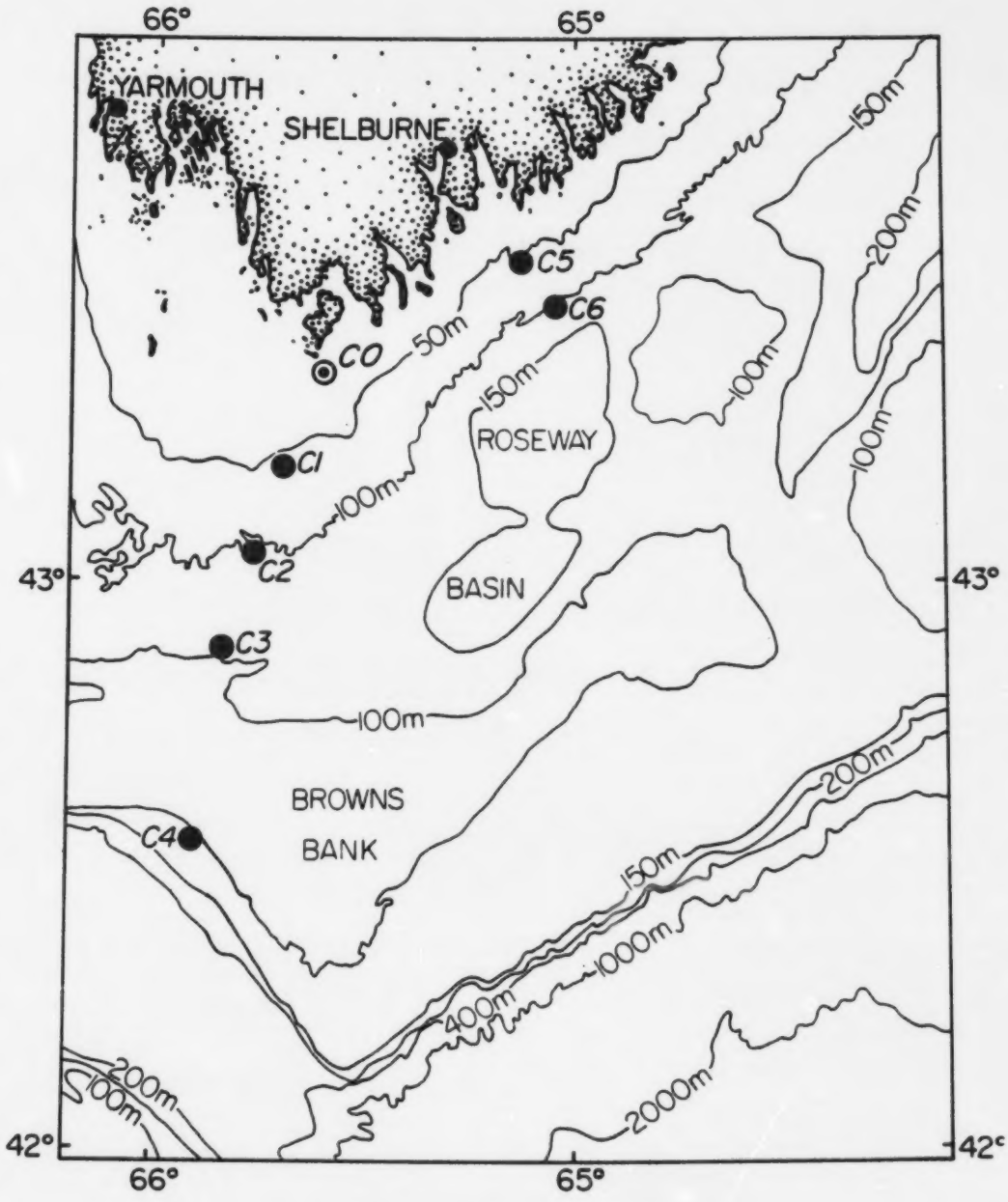


Figure 1 Mooring Array for Cape Sable Experiment

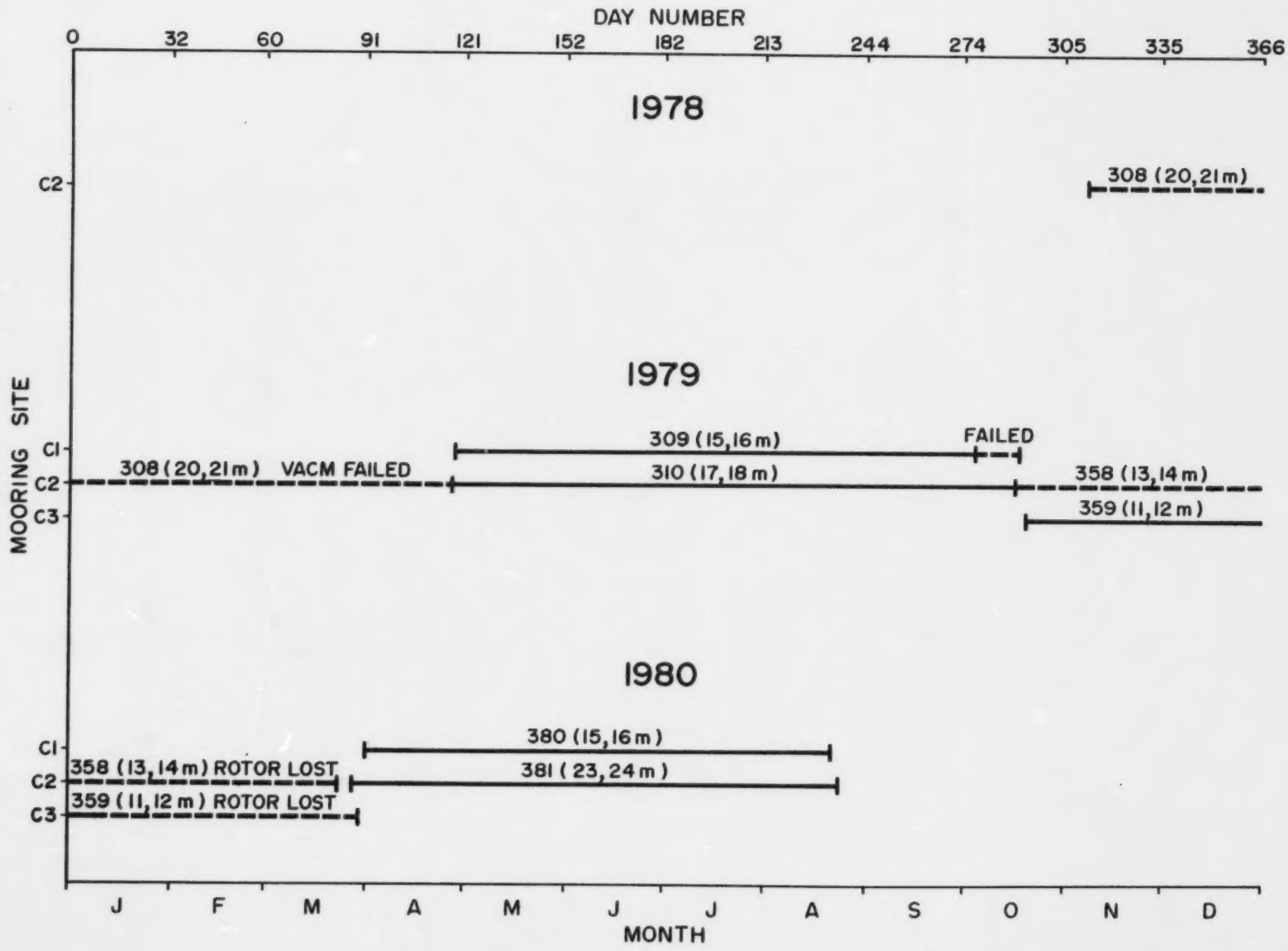


Figure 2 Time Lines for Seven Intercomparison Studies

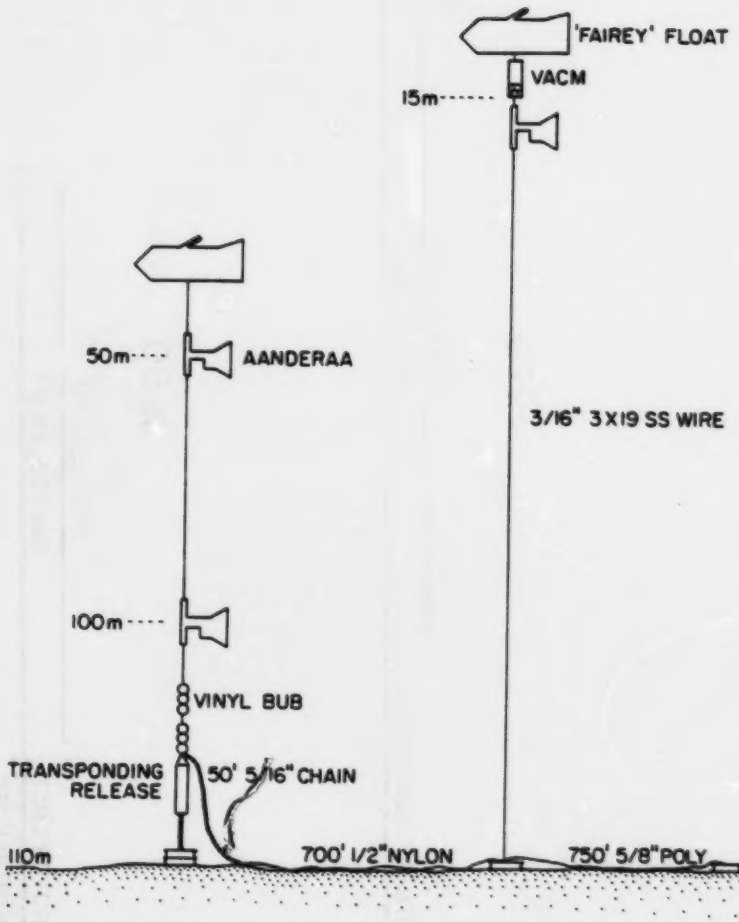


Figure 3 Tri-anchor Configuration for Cape Sable Moorings

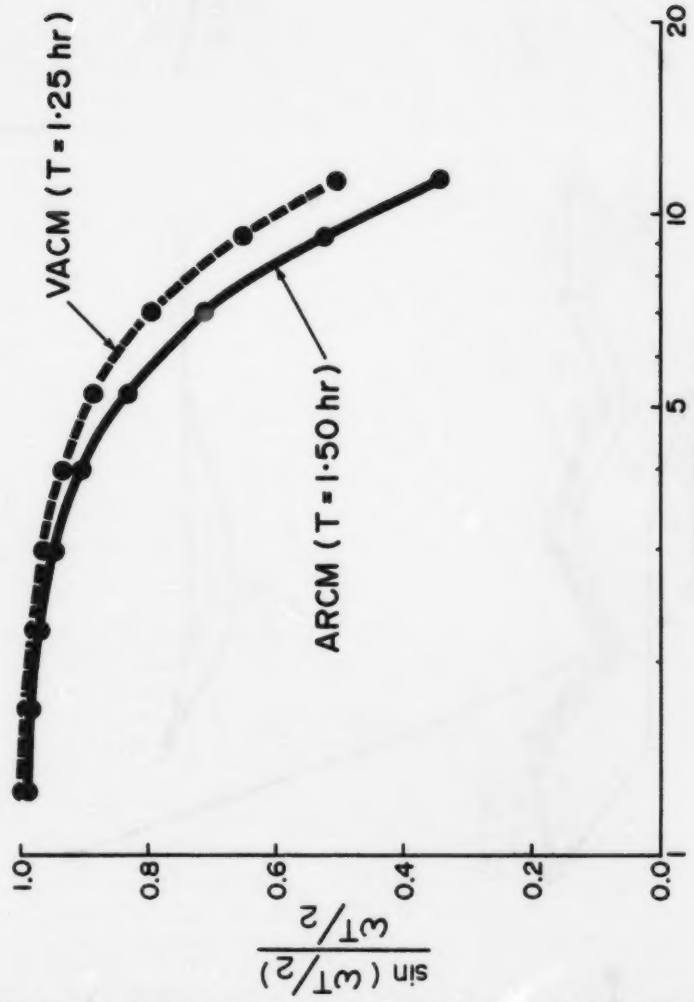


Figure 4 Response Function

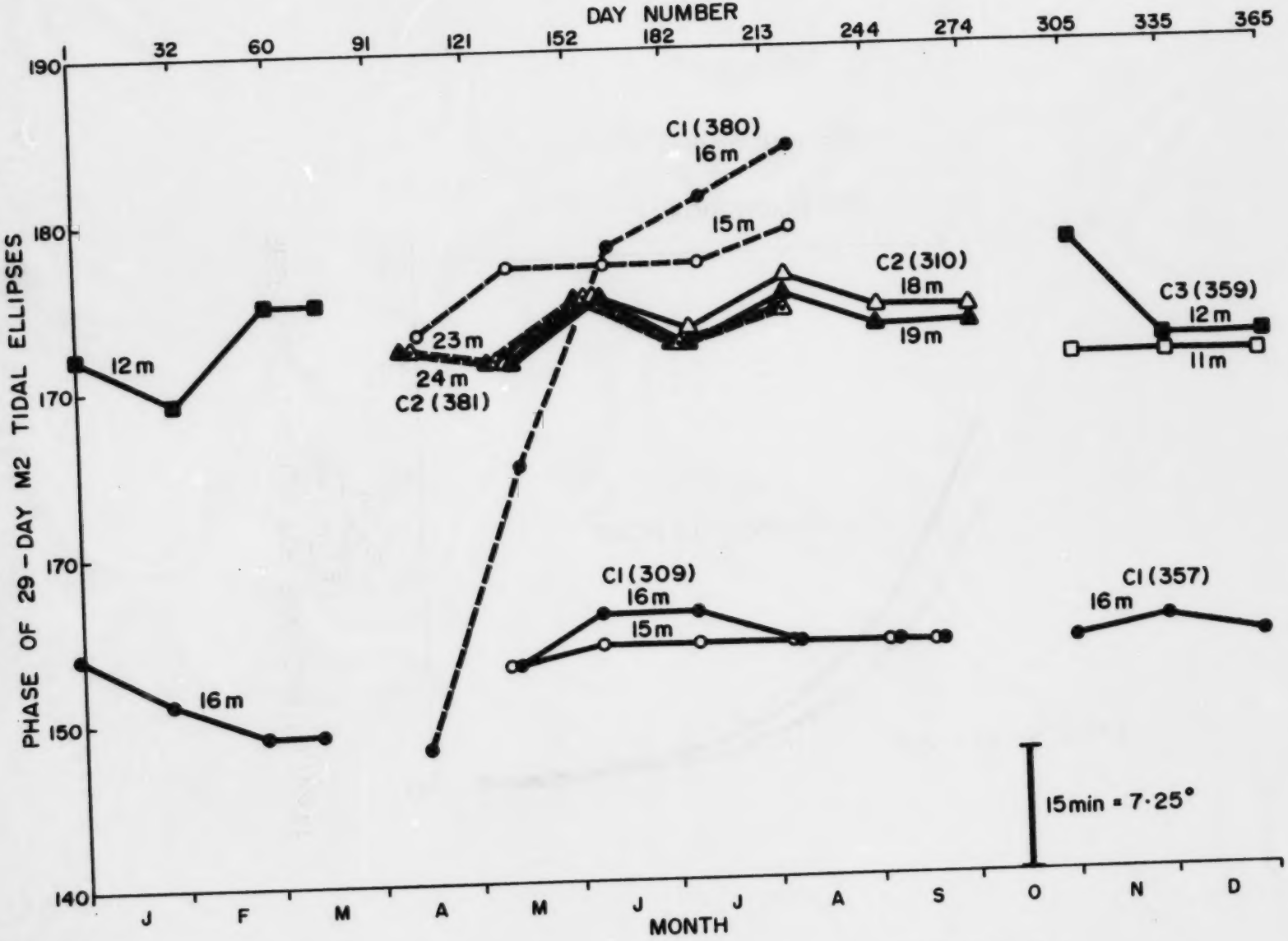


Figure 5 Phase of M_2 Tidal Ellipse from Consecutive 29-day Analyses

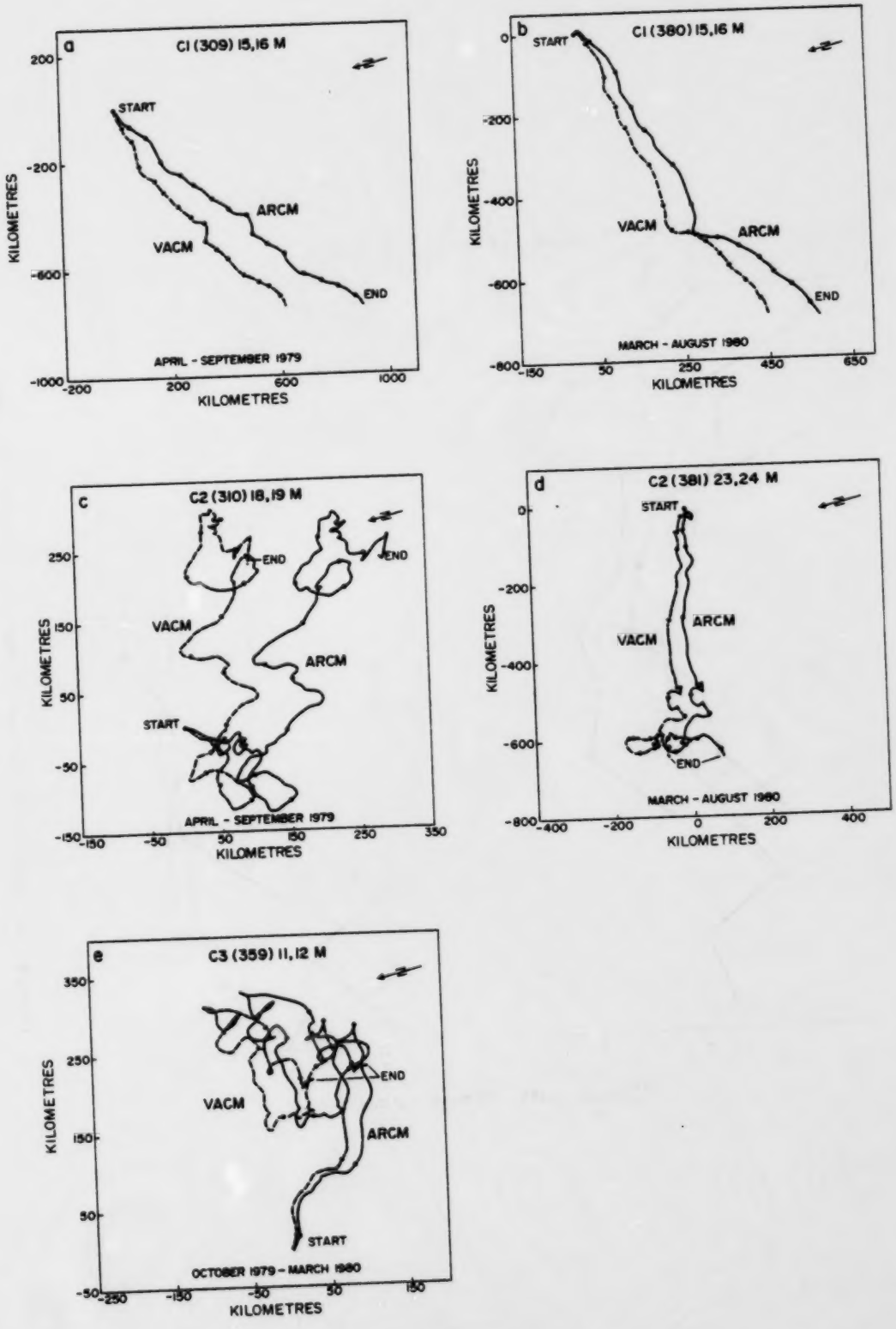


Figure 6 Progressive Vector Diagrams

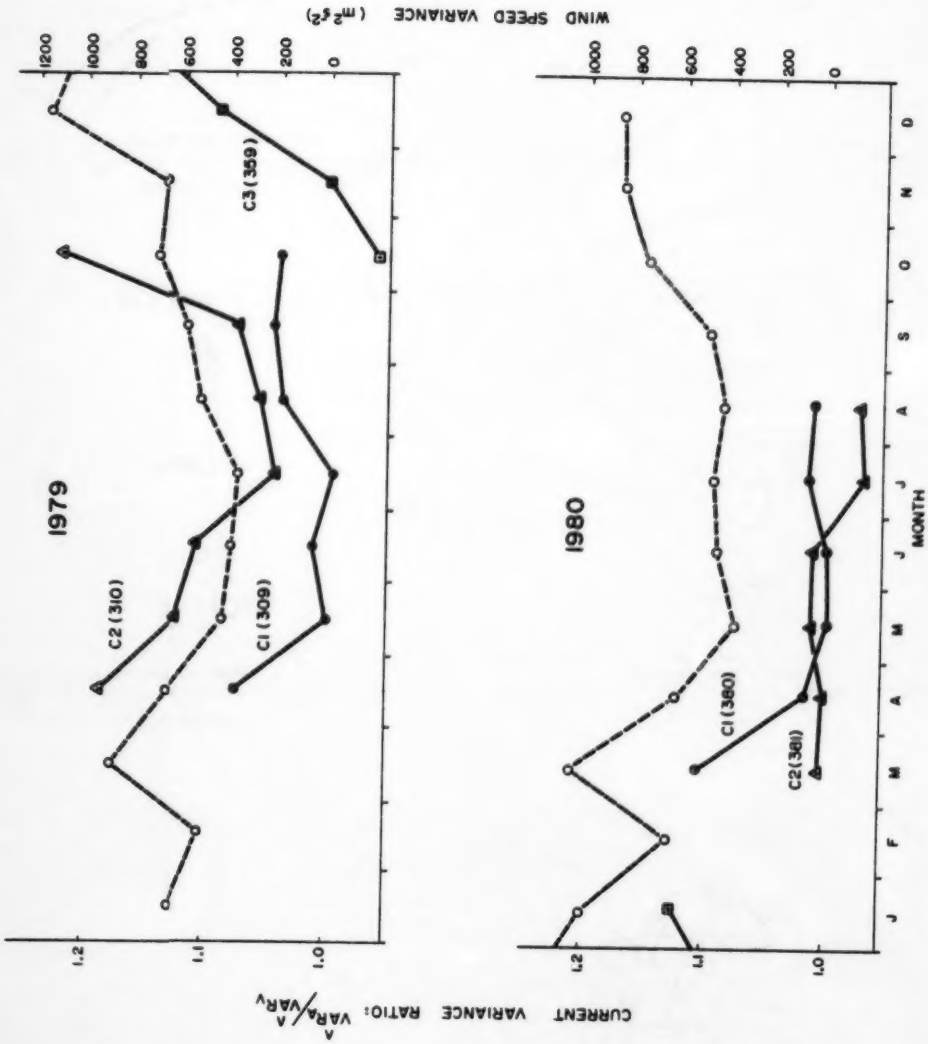


Figure 7a ARCM/VACM Ratios of Monthly Current Variance

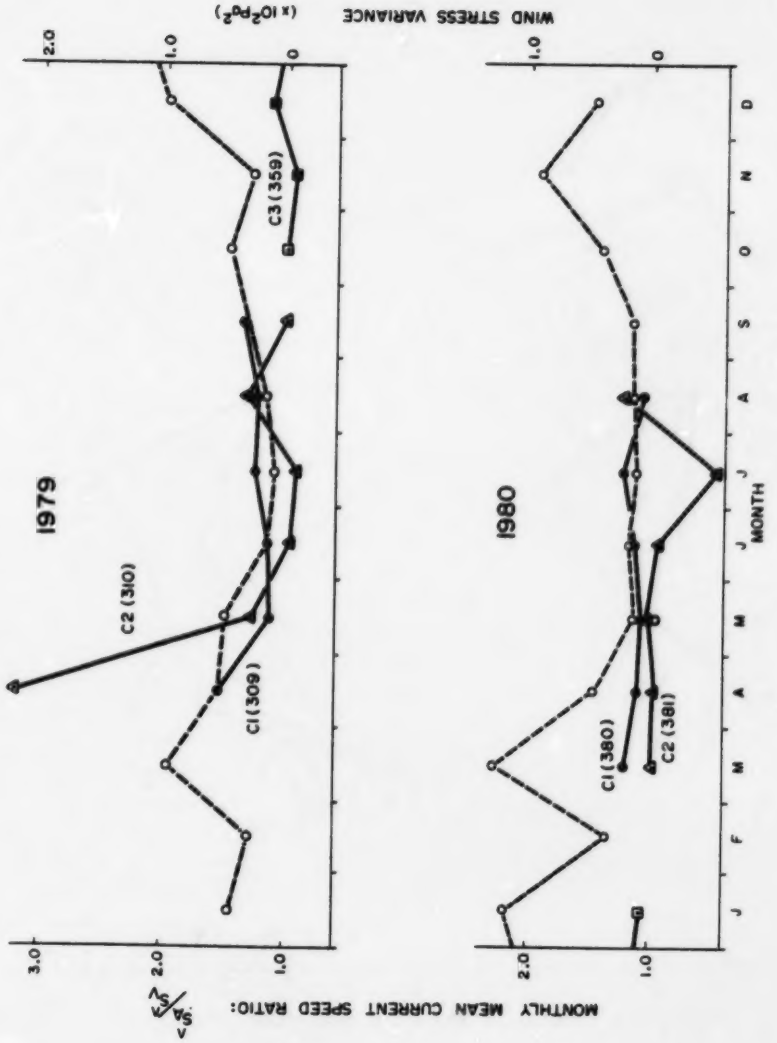


Figure 7b ARCH/VACM Ratio of Monthly Mean Current Speed

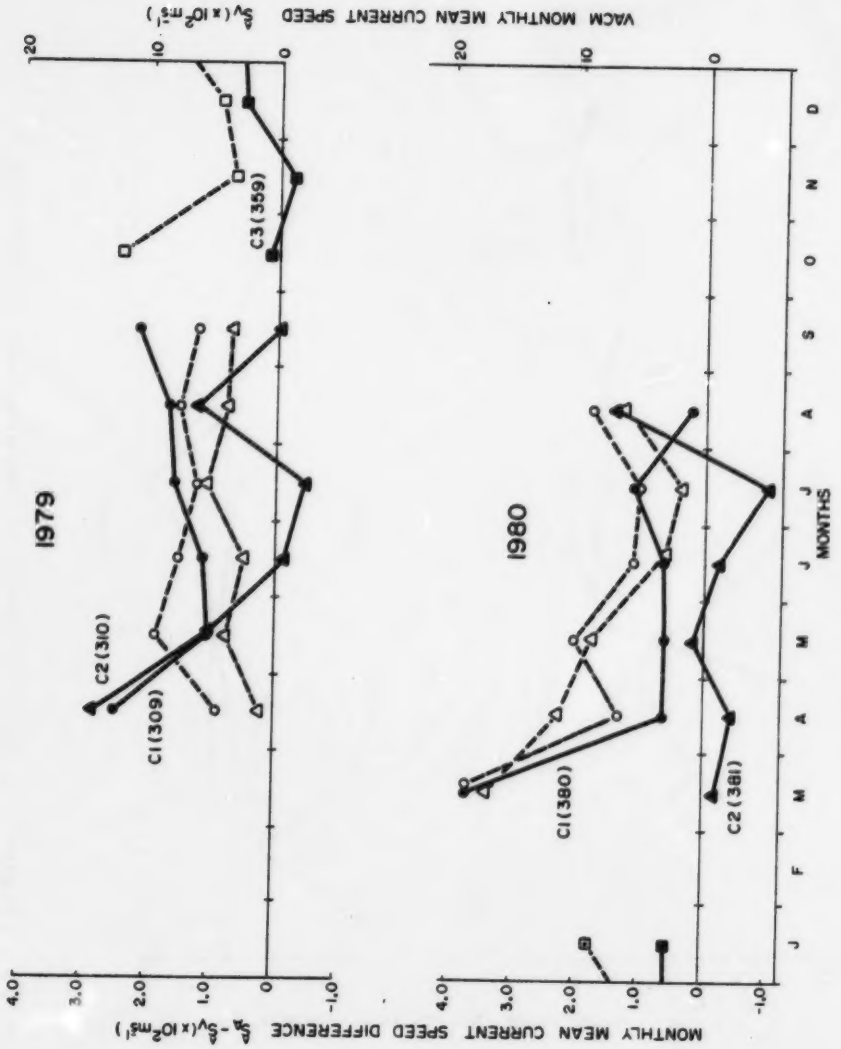


Figure 7c ARCM-VACM Difference and Absolute VACM Value of Monthly Mean Current Speed

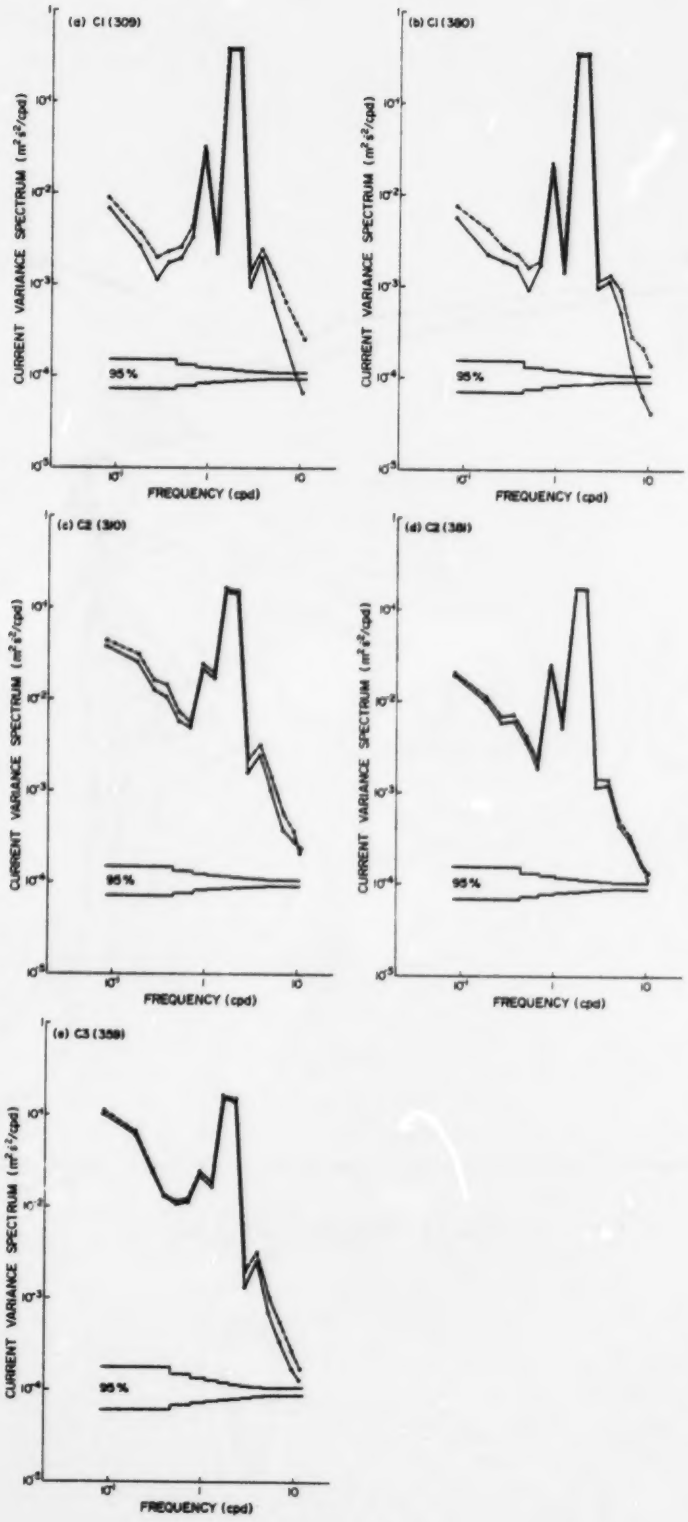


Figure 8 Total Current Variance Spectra
ARCM (dashed) VACM (solid)

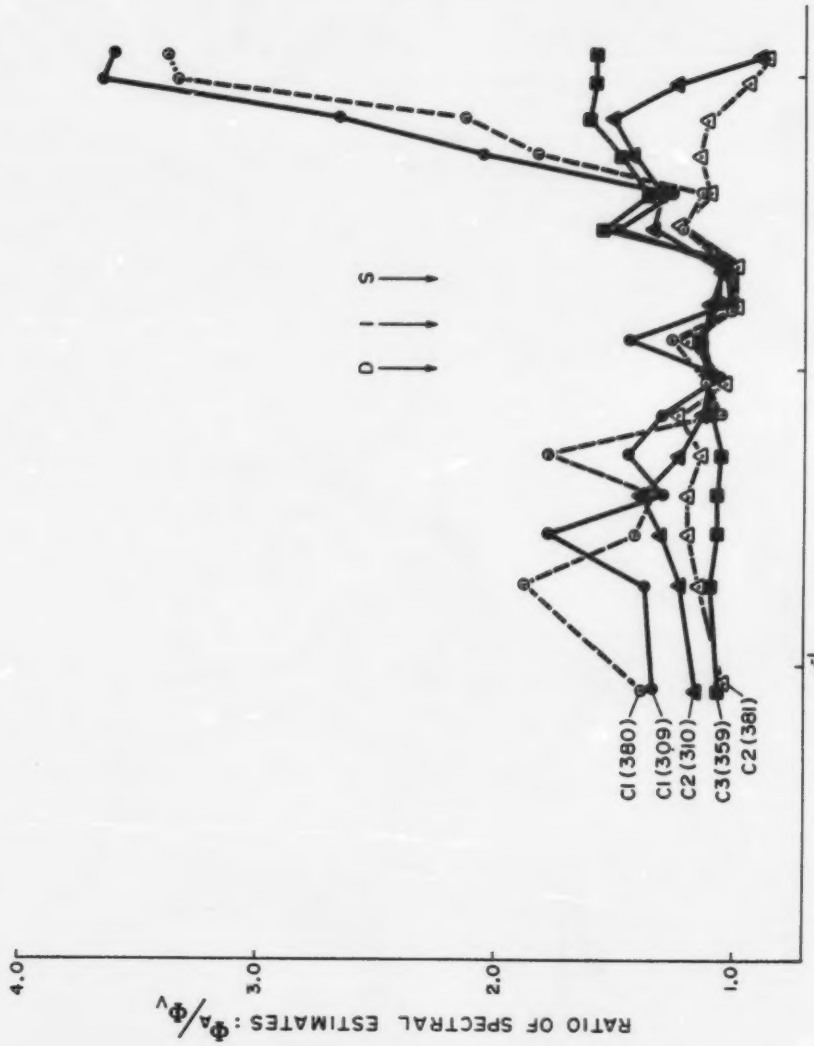


Figure 9 ARCM/VACM Ratio of Special Estimates of Total Current Variance

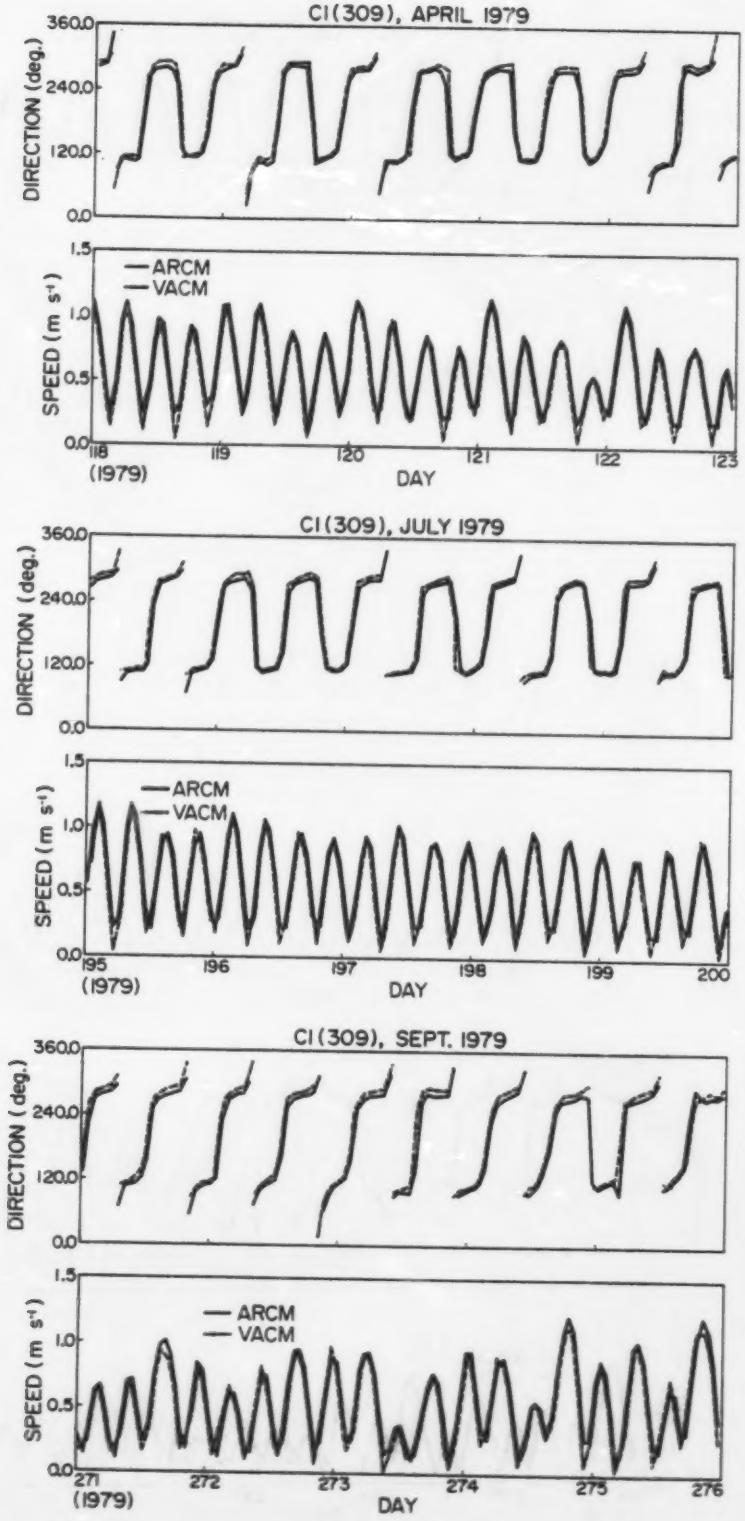


Figure 10 Five-day Time Series at C1

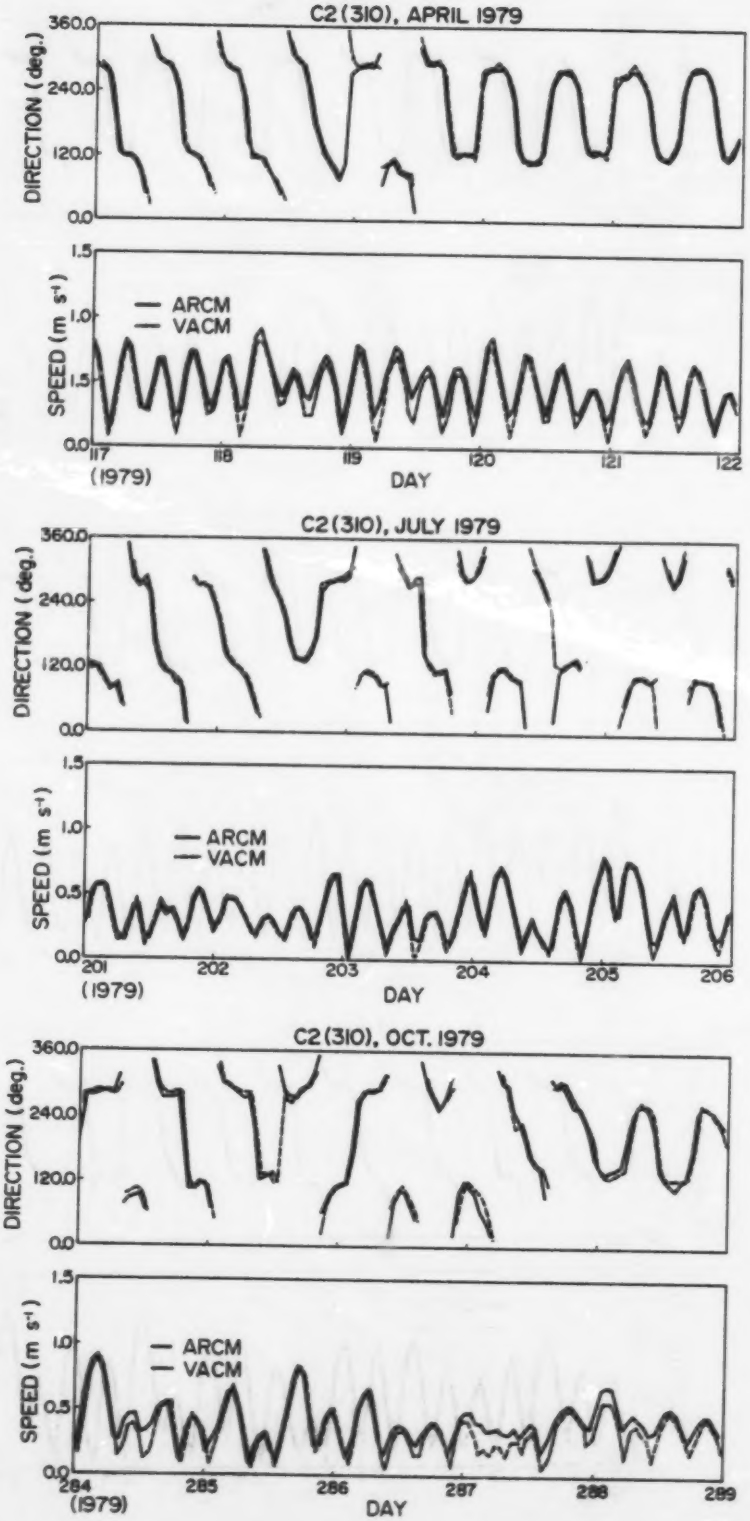


Figure 11 Five-day Time Series at C2

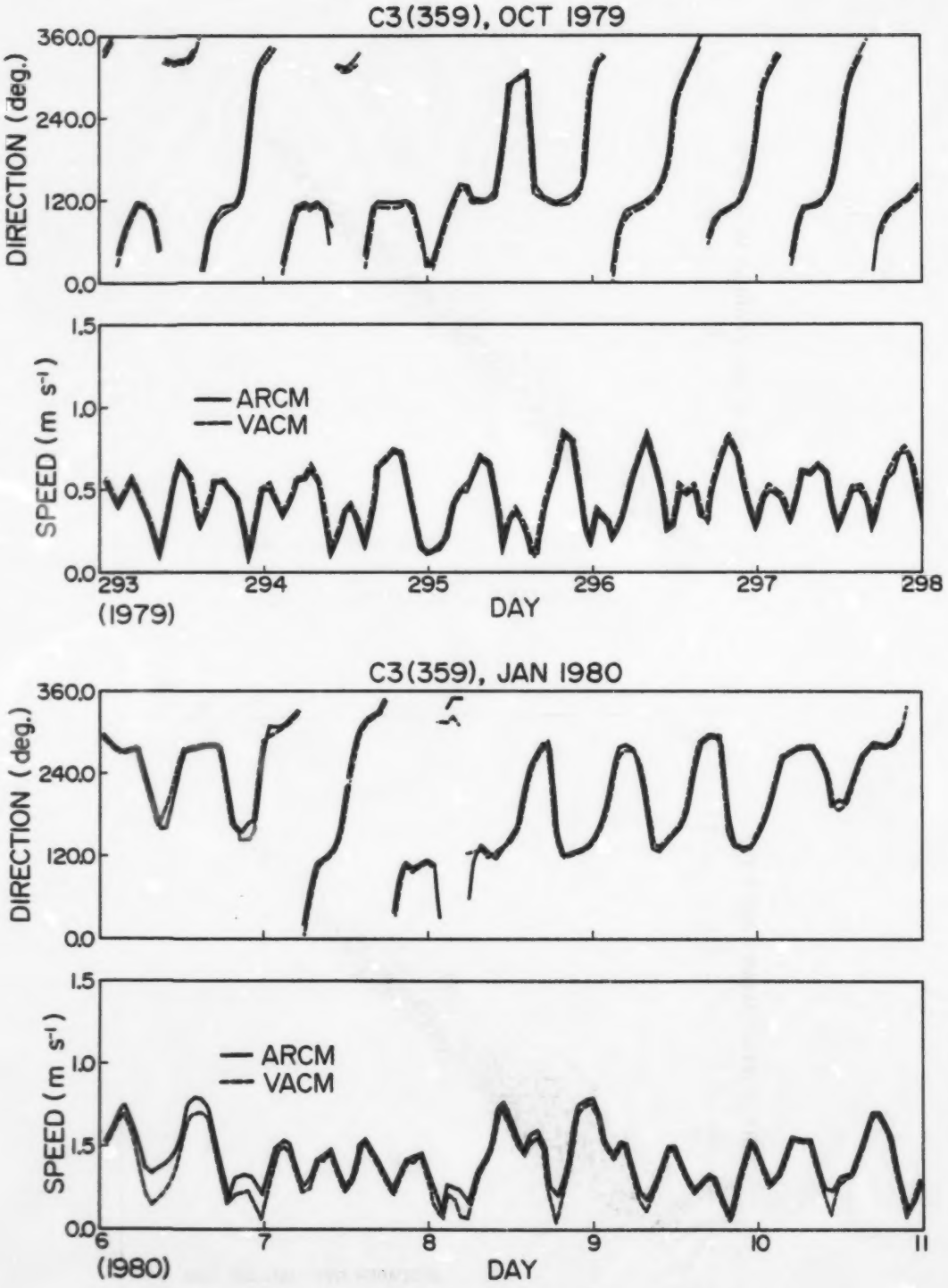
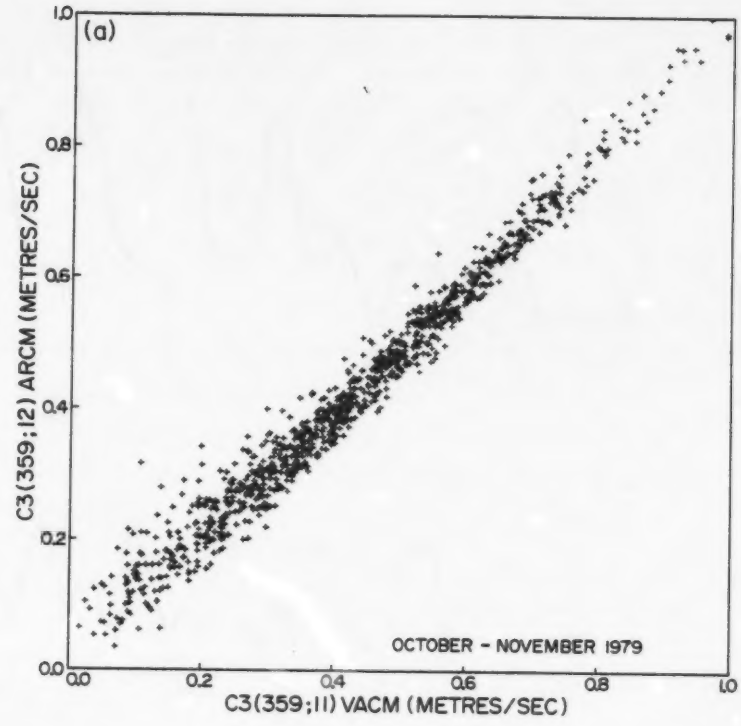


Figure 12 Five-day Time Series at C3



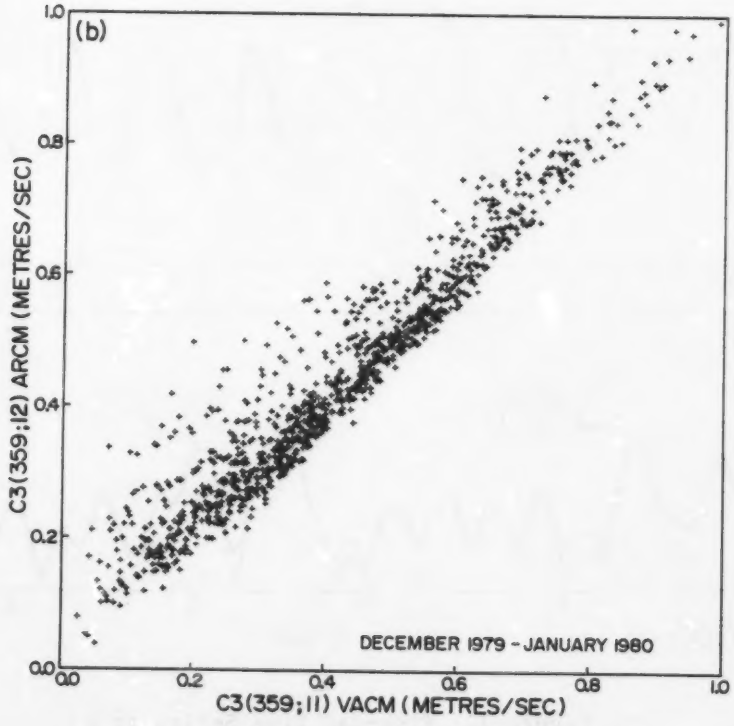


Figure 13 Scatter Plots of Hourly ARCM Scalar vs VACM Vector Speed